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Abstract

THE MECHANISM OF NUCLEATE BOILING

by

Dr. C.J. Rallis[1] and Mr. H.H. Jawurek[2]

Department of Mechanical Engineering, University of the Witwatersrand, Johannesburg

Before the full potential of boiling as a means of heat transfer can be realized it is necessary to have an understanding of its basic mechanism. This paper represents an attempt to approach the problem in a simple and direct manner. Only the simplest case of boiling, that is, nucleate boiling under saturated pool conditions, is dealt with. Treatment of this simple case is considered a prerequisite to any more advanced study of boiling.

For many years latent heat transport, defined by

$$(q/A)_{LH} = \rho_v \lambda_v \sum_{i=1}^{n} f_i V_{di} / A = N \overline{fV}_d \rho_v \lambda_v$$

has been considered to contribute negligibly to the total heat flux under all nucleate boiling conditions. Experimental results on nucleate pool boiling at saturation, reported herein, indicate that the ratio $(q/A)_{LH}/(q/A)_{Tot}$ increases steadily with increasing flux, tending to unity as $(q/A)_{Tot}$ tends towards burnout. Latent heat transport and convection together account for the total flux

[1]Senior Lecturer. [2]South African Atomic Energy Board Bursar

is saturated boiling.

The bulk of this paper deals with the parameters entering into the formulation of $(q/A)_{LH}$. Inevitably these must also have a bearing on any bubble-induced convection mechanism.

The two most important parameters entering into $(q/A)_{LH}$ are (i) the bubble source concentration, N, which is primarily surface-dependent, and (ii) the mean mass flow rate from each source, $\overline{fV}_d\rho_v$, which is essentially hydrodynamic in nature. However, these two parameters are interrelated.

Experimental results show that (i) the arithmetic mean product $\overline{fV}_d$ increases with flux, and (ii) at a particular flux the product fV_d is approximately the same for each bubble source.

The term N, the bubble source concentration, is of prime importance from the point of view of heat transfer correlation, in that it enters both into the formulation for latent heat transport, and into that for convection as the number of liquid-flow inducing sources. In the region of isolated bubbles the bubble source concentration, N, is identical with the nucleation site concentration, $\mathcal{N}$; at higher fluxes this is no longer the case, since vapour from several nuclei can coalesce to form only one bubble. The relation

$$(q/A)_{Tot} = \text{const.}\mathcal{N}^n$$

where $n \simeq 0.5$ is confirmed for water boiling at atmospheric pressure and for organics at various low pressures.

Using this relation and an equation characterizing nucleation from a cavity, and given a boiling curve, it is found possible to arrive at the size distribution of potentially active nucleation cavities; that is, a surface can be characterized with respect to nucleation. Data on both $\mathcal{N}$ and N, and hence coalescence, are presented.

Analysis using the nucleation equation indicates that nucleation and hence nucleate boiling cannot be made to proceed indefinitely at lower and lower pressures; for a given surface-liquid combination a pressure exists below which nucleation cannot proceed in the normal sense. Confirmatory experiments show that this pressure marks the threshold of a hitherto unrecognized regime of unstable nucleate boiling. At lower pressure the nucleate regime is altogether absent.

Whilst still in the early stages of development, the study here reported illustrates the lines along which a rational nucleate boiling heat transfer correlation could be obtained.